Scala 3 enum for a terser Option Monad Algebraic Data Type

- Explore a terser definition of the **Option Monad** that uses a **Scala 3 enum** as an **Algebraic Data Type**.
- In the process, have a tiny bit of fun with **Scala 3 enums**.
- Get a refresher on the **Functor** and **Monad** laws.
- See how easy it is to use **Scala 3 extension** methods, e.g. to add convenience methods and infix operators.

slides by  **@philip_schwarz**

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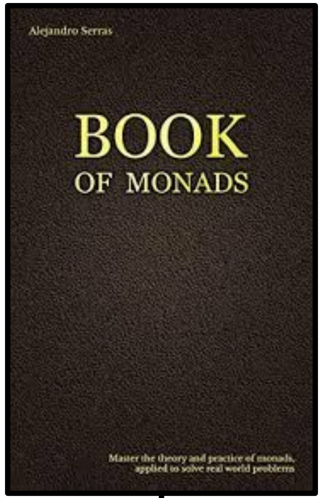
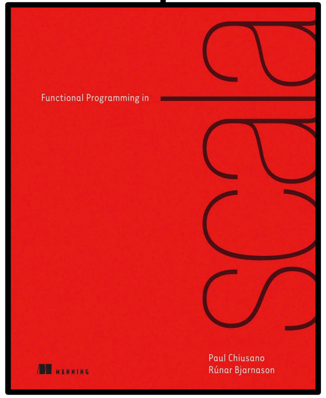
We introduce a new type, **Option**. As we mentioned earlier, this type also exists in the **Scala** standard library, but we're re-creating it here for pedagogical purposes:

```
sealed trait Option[+A]
case class Some[+A](get: A) extends Option[A]
case object None extends Option[Nothing]
```

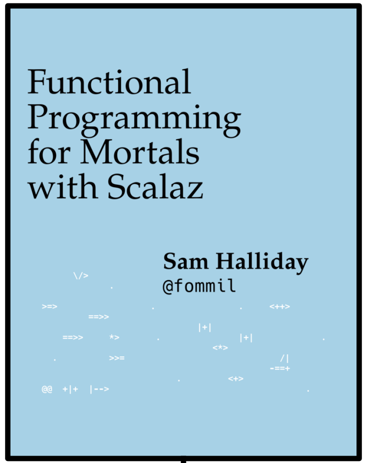
Option is mandatory! Do not use **null** to denote that an optional value is absent. Let's have a look at how **Option** is defined:

```
sealed abstract class Option[+A] extends IterableOnce[A]
final case class Some[+A](value: A) extends Option[A]
case object None extends Option[Nothing]
```





Over the years we have all got very used to the definition of the **Option monad**'s **Algebraic Data Type** (**ADT**).



Since creating new data types is so cheap, and it is possible to work with them polymorphically, most functional languages define some notion of an **optional value**. In **Haskell** it is called **Maybe**, in **Scala** it is **Option**, … Regardless of the language, the structure of the data type is similar:

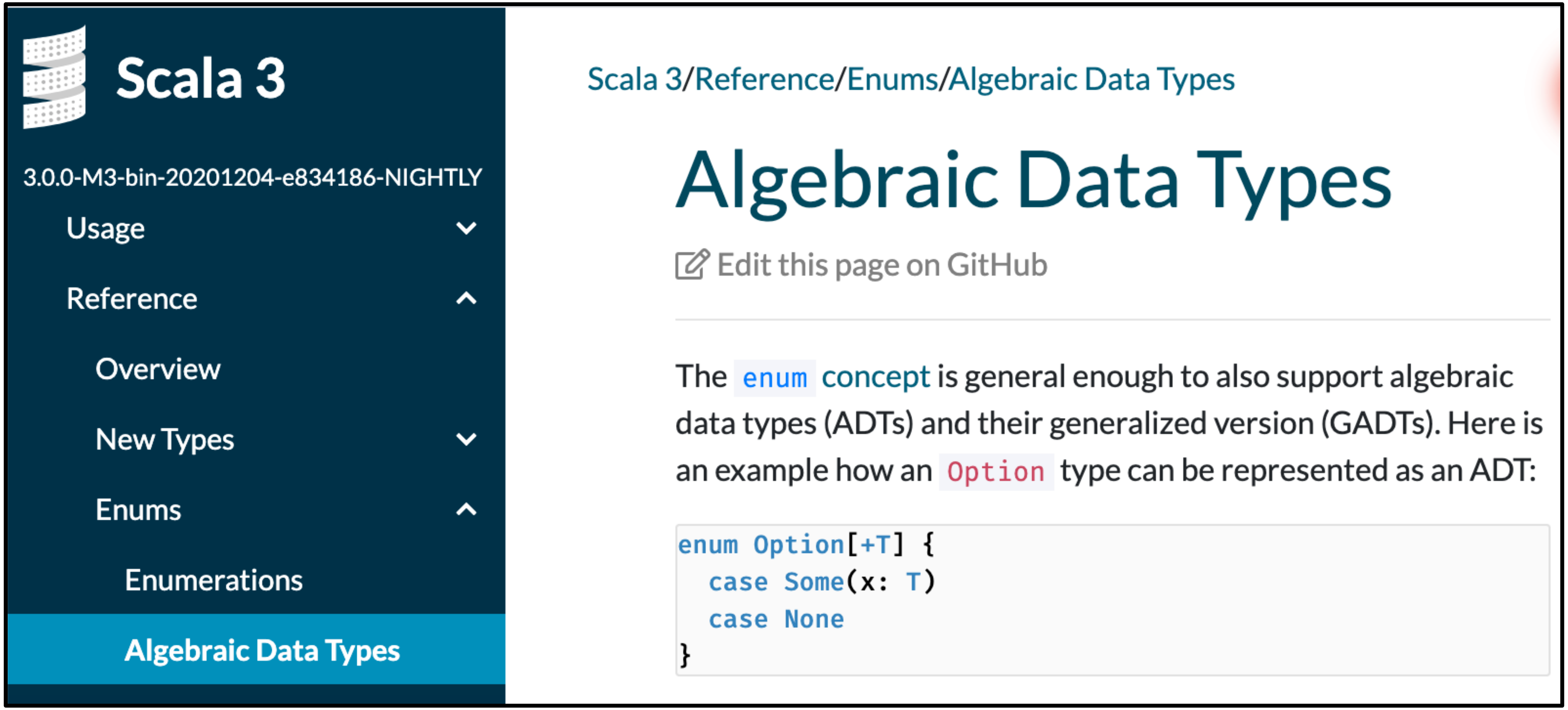
```
data Maybe a = Nothing -- no value
             | Just a  -- holds a value

sealed abstract class Option[+A]                  // optional value
case object None extends Option[Nothing]          // no value
case class Some[A](value: A) extends Option[A] // holds a value
```

We have already encountered **scalaz**'s improvement over `scala.Option`, called **Maybe**. It is an improvement because it does not have any unsafe methods like **Option.get**, which can throw an exception, and is invariant.

It is typically used to represent when a thing may be present or not without giving any extra context as to why it may be missing.

```
sealed abstract class Maybe[A] { ... }
object Maybe {
  final case class Empty[A]() extends Maybe[A]
  final case class Just[A](a: A) extends Maybe[A]
```

With the arrival of **Scala 3** however, the definition of the **Option ADT** becomes much terser thanks to the fact that it can be implemented using the new **enum** concept .



Scala 3

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Usage

Reference

Overview

New Types

Enums

Enumerations

Algebraic Data Types

Scala 3/Reference/Enums/Algebraic Data Types

Algebraic Data Types

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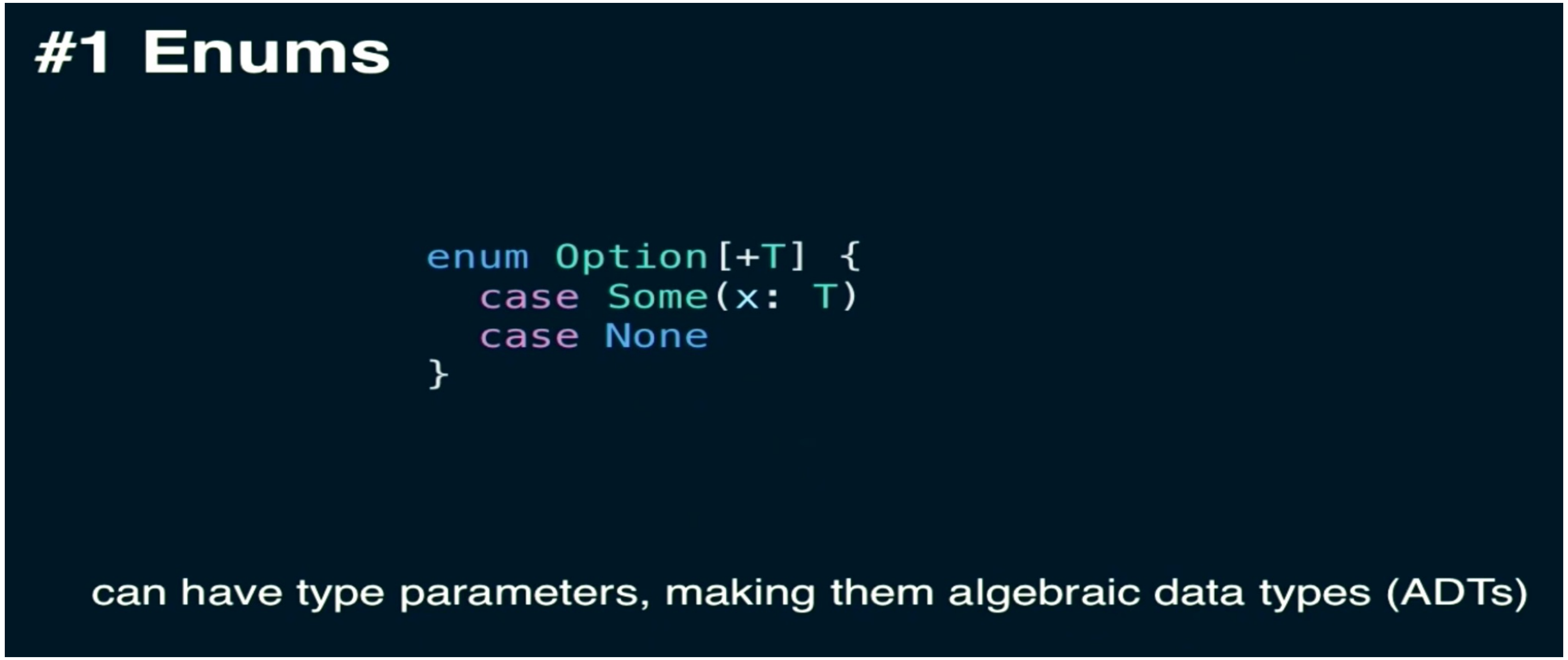
The `enum` concept is general enough to also support algebraic data types (ADTs) and their generalized version (GADTs). Here is an example how an `Option` type can be represented as an ADT:

```
enum Option[+T] {
  case Some(x: T)
  case None
}
```

Martin Odersky
@odersky

OK, so this is, again, cool, **now we have parity with Java**, **but we can actually go way further**. **enums can not only have value parameters, they also can have type parameters, like this**.



YouTube A Tour of Scala 3 – by Martin Odersky

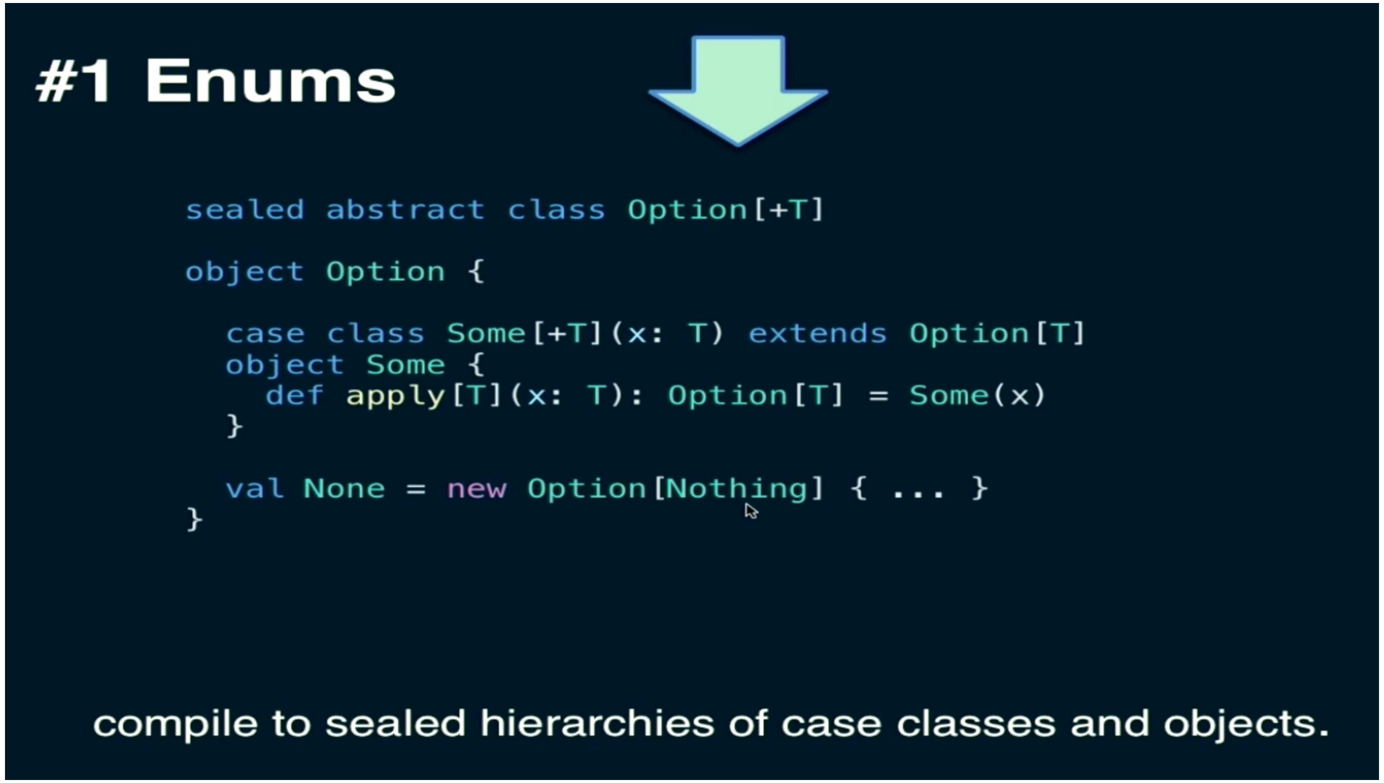
So you can have an **enum** **`Option`** with a **covariant** type parameter **T** and then two cases **Some** and **None**.

So that of course gives you what people call an Algebraic Data Type, or ADT.

Scala so far was lacking a simple way to write an ADT. What you had to do is essentially what the compiler would translate this to.

Martin Odersky
@odersky

So the compiler would take this **ADT** that you have seen here and translate it into essentially this:



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And so far, if you wanted something like that, you would have written essentially the same thing. So **a sealed abstract class or a sealed abstract trait**, **`Option`**, **with a case class as one case, and as the other case, here it is a val, but otherwise you could also use a case object**.

And **that of course is completely workable, but it is kind of tedious**. **When Scala started, one of the main motivations, was to avoid pointless boilerplate**. So that's why **case classes** were invented, and **a lot of other innovations that just made code more pleasant to write and more compact than Java code**, the standard at the time.

@philip_schwarz

On the next slide we have a go at adding some essential methods to this terser **enum**-based `Option` **ADT**.

```
enum Option[+A]:
  case Some(a: A)
  case None
```

Option is a monad, so we have given it a flatMap method and a pure method. In Scala the latter is not strictly needed, but we'll make use of it later.

Every monad is also a functor, and this is reflected in the fact that we have given Option a map method.

We gave Option a fold method, to allow us to interpret/execute the Option effect, i.e. to escape from the Option container, or as John a De Goes puts it, to translate away from optionality by providing a default value.

We want our Option to integrate with for comprehensions sufficiently well for our current purposes, so in addition to map and flatMap methods, we have given it a simplistic withFilter method that is just implemented in terms of filter, another pretty essential method.

There are of course many many other methods that we would normally want to add to Option.

```
enum Option[+A]:
  case Some(a: A)
  case None

  def map[B](f: A => B): Option[B] =
    this match
      case Some(a) => Some(f(a))
      case None => None

  def flatMap[B](f: A => Option[B]): Option[B] =
    this match
      case Some(a) => f(a)
      case None => None

  def fold[B](ifEmpty: => B)(f: A => B) =
    this match
      case Some(a) => f(a)
      case None => ifEmpty

  def filter(p: A => Boolean): Option[A] =
    this match
      case Some(a) if p(a) => Some(a)
      case _ => None

  def withFilter(p: A => Boolean): Option[A] =
    filter(p)

object Option :
  def pure[A](a: A): Option[A] = Some(a)
  def none: Option[Nothing] = None

extension[A](a: A):
  def some: Option[A] = Some(a)
```

The some and none methods are just there to provide the convenience of Cats-like syntax for lifting a pure value into an Option and for referring to the empty Option instance.

Yes, the **some** method on the previous slide was implemented using the new **Scala 3** feature of **Extension Methods**.

Scala 3

3.0.0-M3-bin-20201204-e834186-NIGHTLY

- New Types
- Enums
- Contextual Abstractions
  - Overview
  - Given Instances
  - Using Clauses
  - Context Bounds
  - Importing Givens
  - **Extension Methods**

Scala 3/Reference/Contextual Abstractions/Extension Methods

Extension Methods

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Extension methods allow one to add methods to a type after the type is defined. Example:

```
case class Circle(x: Double, y: Double, radius: Double)

extension (c: Circle)
  def circumference: Double = c.radius * math.Pi * 2
```

Like regular methods, extension methods can be invoked with infix `.`:

```
val circle = Circle(0, 0, 1)
circle.circumference
```

On the next slide we do the following:

- See our **Option monad ADT** again
- Define a few **enumerated types** using use the **Scala 3 enum** feature.
- Add a simple program showing the **Option monad** in action.

```scala
enum Option[+A]:
  case Some(a: A)
  case None

  def map[B](f: A => B): Option[B] =
    this match
      case Some(a) => Some(f(a))
      case None => None

  def flatMap[B](f: A => Option[B]): Option[B] =
    this match
      case Some(a) => f(a)
      case None => None

  def fold[B](zero: => B)(f: A => B) =
    this match
      case Some(a) => f(a)
      case None => zero

  def filter(p: A => Boolean): Option[A] =
    this match
      case Some(a) if p(a) => Some(a)
      case _ => None

  def withFilter(p: A => Boolean): Option[A] =
    filter(p)

object Option :
  def pure[A](a: A): Option[A] = Some(a)
  def none: Option[Nothing] = None

extension[A](a: A):
  def some: Option[A] = Some(a)
```

```scala
enum Greeting(val language: Language):
  override def toString: String =
    s"${enumLabel} ${language.toPreposition}"
  case Welcome     extends Greeting(English)
  case Willkommen  extends Greeting(German)
  case Bienvenue   extends Greeting(French)
  case Bienvenido  extends Greeting(Spanish)
  case Benvenuto   extends Greeting(Italian)
```

```scala
enum Language(val toPreposition: String):
  case English extends Language("to")
  case German  extends Language("nach")
  case French  extends Language("à")
  case Spanish extends Language("a")
  case Italian extends Language("a")
```

```scala
enum Planet:
  case Mercury, Venus, Earth, Mars, Jupiter, Saturn, Neptune, Uranus, Pluto, Scala3
```

```scala
case class Earthling(name: String, surname: String, languages: Language*)
```

```scala
def greet(maybeGreeting:   Option[Greeting],
          maybeEarthling: Option[Earthling],
          maybePlanet:      Option[Planet]): Option[String] =
  for
    greeting   <- maybeGreeting
    earthling  <- maybeEarthling
    planet     <- maybePlanet
    if earthling.languages contains greeting.language
  yield s"$greeting $planet ${earthling.name}!"
```

```scala
@main def main =

  val maybeGreeting =
    greet(  maybeGreeting = Some(Welcome),
           maybeEarthling = Some(Earthling("Fred", "Smith", English, Italian)),
              maybePlanet = Some(Scala3))

  println(maybeGreeting.fold("Error: no greeting message")
                            (msg => s"*** $msg ***"))
```

```
*** Welcome to Scala3 Fred! ***
```

```scala
def greet(maybeGreeting:   Option[Greeting],
          maybeEarthling:  Option[Earthling],
          maybePlanet:     Option[Planet]): Option[String] =
  for
    greeting   <- maybeGreeting
    earthling  <- maybeEarthling
    planet     <- maybePlanet
    if earthling.languages contains greeting.language
  yield s"$greeting $planet ${earthling.name}!"
```

Below are some tests for our simple program.

@philip_schwarz

```scala
//            Greeting          Earthling                                            Planet          Greeting Message
assert(greet(Some(Welcome),    Some(Earthling("Fred", "Smith", English, Italian)), Some(Scala3)) == Some("Welcome to Scala3 Fred!"))
assert(greet(Some(Benvenuto),  Some(Earthling("Fred", "Smith", English, Italian)), Some(Scala3)) == Some("Benvenuto a Scala3 Fred!"))
assert(greet(Some(Bienvenue),  Some(Earthling("Fred", "Smith", English, Italian)), Some(Scala3)) == None)
assert(greet(None,             Some(Earthling("Fred", "Smith", English, Italian)), Some(Scala3)) == None)
assert(greet(Some(Welcome),    None,                                               Some(Scala3)) == None)
assert(greet(Some(Welcome),    Some(Earthling("Fred", "Smith", English, Italian)), None)         == None)
```

Same again, but this time using the **some** and **none** convenience methods.

```scala
assert(greet(Welcome.some,   Earthling("Fred", "Smith", English, Italian).some, Scala3.some) == ("Welcome to Scala3 Fred!").some)
assert(greet(Benvenuto.some, Earthling("Fred", "Smith", English, Italian).some, Scala3.some) == ("Benvenuto a Scala3 Fred!").some)
assert(greet(Bienvenue.some, Earthling("Fred", "Smith", English, Italian).some, Scala3.some) == none)
assert(greet(none,           Earthling("Fred", "Smith", English, Italian).some, Scala3.some) == none)
assert(greet(Welcome.some,   none,                                              Scala3.some) == none)
assert(greet(Welcome.some,   Earthling("Fred", "Smith", English, Italian).some, none)        == none)
```

The remaining slides provide us with a refresher of the **functor** and **monad laws**. To do so, they use two examples of ordinary functions and three examples of **Kleisli arrows**, i.e. functions whose signature is of the form A => F[B], for some **monad** F, which in our case is the **Option monad**.

The example functions are defined below, together with a function that uses them. While the functions are bit contrived, they do the job.

The reason why the **Kleisli arrows** are a bit more complex than would normally be expected is that since in this slide deck we are defining our own simple **Option monad**, we are not taking shortcuts that involve the standard **Scala Option**, e.g. converting a **String** to an **Int** using the **toIntOption** function available on **String**.

```scala
val double: Int => Int = n => 2 * n
val square: Int => Int = n => n * n
```

```scala
val stringToInt: String => Option[Int] = s =>
  Try { s.toInt }.fold(_ => None, Some(_))
```

```scala
assert( stringToInt("123") == Some(123) )
assert( stringToInt("1x3") == None )
```

```scala
val intToChars: Int => Option[List[Char]] = n =>
  if n < 0 then None
           else Some(n.toString.toArray.toList)
```

```scala
assert( intToChars(123) == Some(List('1', '2', '3')))
assert(   intToChars(0) == Some(List('0')))
assert( intToChars(-10) == None)
```

```scala
val charsToInt: Seq[Char] => Option[Int] = chars =>
  Try {
    chars.foldLeft(0){ (n,char) => 10 * n + char.toString.toInt }
  }.fold(_ => None, Some(_))
```

```scala
assert(charsToInt(List('1', '2', '3')) == Some(123) )
assert(charsToInt(List('1', 'x', '3')) == None )
```

```scala
def doublePalindrome(s: String): Option[String] =
  for
            n <- stringToInt(s)
        chars <- intToChars(2 * n)
    palindrome <- charsToInt(chars ++ chars.reverse)
  yield palindrome.toString
```

```scala
assert( doublePalindrome("123") == Some("246642") )
assert( doublePalindrome("1x3") == None )
```

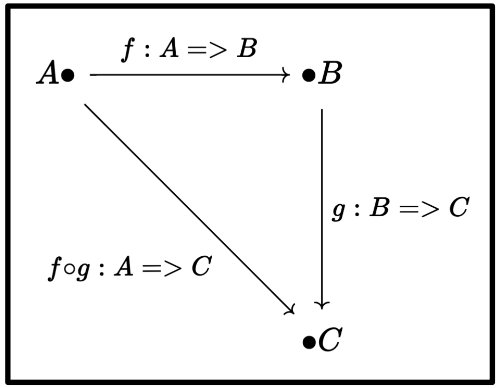
Since every **monad** is also a **functor**, the next slide is a reminder of the **functor** laws.

We also define a **Scala 3 extension method** to provide syntax for the infix operator for **function composition**.

```
// FUNCTOR LAWS

// identity law: ma map identity = identity(ma)
assert( (f(a) map identity) == identity(f(a)) )
assert( (a.some map identity) == identity(a.some) )
assert( (none map identity) == identity(none) )

// composition law: ma map (g ∘ h) == ma map h map g
assert( (f(a) map (g ∘ h)) == (f(a) map h map g) )
assert( (3.some map (g ∘ h)) == (3.some map h map g) )
assert( (none map (g ∘ h)) == (none map h map g) )
```




```
val f = stringToInt
val g = double
val h = square
val a = "123"

// plain function composition
extension[A,B,C](f: B => C)
  def ∘ (g: A => B): A => C =
    a => f(g(a))

def identity[A](x: A): A = x
```

```
assert( stringToInt("123") == Some(123) )
assert( stringToInt("1x3") == None )
```

```
val double: Int => Int = n => 2 * n
val square: Int => Int = n => n * n
```

```
enum Option[+A]:
  case Some(a: A)
  case None

  def map[B](f: A => B): Option[B] =
    this match
      case Some(a) => Some(f(a))
      case None => None

  ...

object Option :
  def pure[A](a: A): Option[A] = Some(a)
  def none: Option[Nothing] = None

extension[A](a: A):
  def some: Option[A] = Some(a)
```

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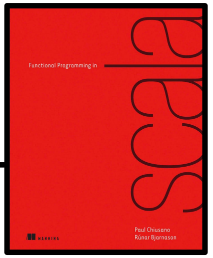
While the **functor Identity Law** is very simple, the fact that it can be formulated in slightly different ways can sometimes be a brief source of puzzlement when recalling the law.

On the next slide I have a go at recapping three different ways of formulating the law.

Functor Identity Law

Scala

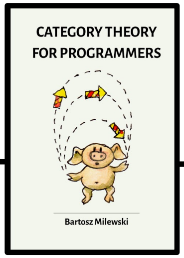
x map (a => a) = x



x map identity = identity(x)

Category Theory

$F(id_X) = id_{F(X)}$



↓

$Option(id_X) = id_{Option(X)}$

↓

$map_{Option}(id_X) = id_{Option(X)}$

↓

$x\ map_{Option}\ (id_X) = id_{Option(X)}(x)$

↓

x map identity = identity(x)

Haskell

fmap id = id

↓

$fmap_F\ id_a = id_{F\ a}$

↓

$fmap_{Maybe}\ id_a = id_{Maybe\ a}$

↓

$fmap_{Maybe}\ id_a\ x = id_{Maybe\ a}\ x$

↓

fmap id x = id x

```
scala> :type Option(3).map
(Int => Any) => Option[Any]
scala> val inc: Int => Int = n => n + 1
scala> Some(3) map inc
val res1: Option[Int] = Some(4)
scala> None map inc
val res2: Option[Int] = None
scala> :type identity
Any => Any
scala> identity(3)
val res3: Int = 3
scala> identity(Some(3))
val res4: Some[Int] = Some(3)
scala> (Some(3) map identity) ==
identity(Some(3))
val res10: Boolean = true
scala> (None map identity) == identity(None)
val res11: Boolean = true
```

Functor

Option — **Maybe**

Some, None — **Just, Nothing**

```
λ> :type fmap
fmap :: Functor f => (a -> b) -> f a -> f b
λ> inc x = x + 1
λ> fmap inc (Just 3)
Just 4
λ> fmap inc Nothing
Nothing
λ> :type id
id :: a -> a
λ> id 3
3
λ> id (Just 3)
Just 3
λ> fmap id Just 3 == id Just 3
True
λ> fmap id Nothing == id Nothing
True
```

The last two slides of this deck remind us of the **monad laws**.

They also make use of **Scala 3 extension methods**, this time to provide syntax for the infix operators for **flatMap** and **Kleisli composition**.

```
// MONAD LAWS

// left identity law: pure(a) flatMap f == f(a)
assert( (pure(a) flatMap f) == f(a) )

// right identity law: ma flatMap pure == ma
assert(   (f(a) flatMap pure) == f(a)    )
assert( (a.some flatMap pure) == a.some )
assert(   (none flatMap pure) == none    )

// associativity law: ma flatMap f flatMap g = ma flatMap (a => f(a) flatMap g)
assert(   ((f(a) flatMap g) flatMap h) ==   (f(a) flatMap (x => g(x) flatMap h)) )
assert( ((3.some flatMap g) flatMap h) == (3.some flatMap (x => g(x) flatMap h)) )
assert(   ((none flatMap g) flatMap h) ==   (none flatMap (x => g(x) flatMap h)) )
```

```
val f = stringToInt
val g = intToChars
val h = charsToInt
val a = "123”
```

```
assert( stringToInt("123") == Some(123) )
assert( stringToInt("1x3") == None )
```

```
assert( intToChars(123) == Some(List('1', '2', '3')))
assert(   intToChars(0) == Some(List('0')))
assert( intToChars(-10) == None)
```

```
assert(charsToInt(List('1', '2', '3')) == Some(123) )
assert(charsToInt(List('1', 'x', '3')) == None )
```

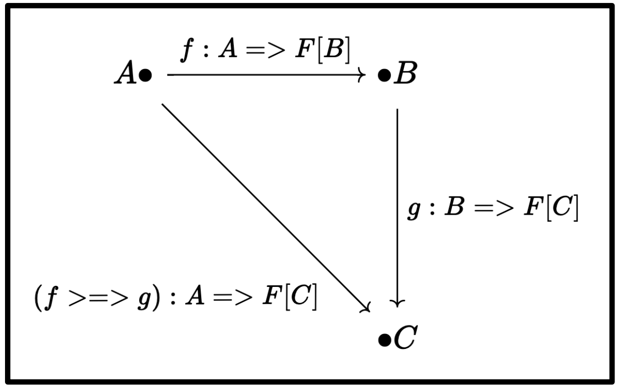
```
enum Option[+A]:
  case Some(a: A)
  case None
  ...

def flatMap[B](f: A => Option[B]): Option[B] =
  this match
    case Some(a) => f(a)
    case None => None
  ...

object Option :
  def pure[A](a: A): Option[A] = Some(a)
  def none: Option[Nothing] = None
  def id[A](oa: Option[A]): Option[A] = oa

extension[A](a: A):
  def some: Option[A] = Some(a)
```

The **monad laws** again, but this time using a **Haskell**-style **bind** operator as an alias for **flatMap**.

```scala
// left identity law: pure(a) flatMap f == f(a)
assert((pure(a) >>= f) == f(a))

// right identity law: ma flatMap pure == ma
assert(   (f(a) >>= pure) == f(a))
assert( (3.some >>= pure) == 3.some)
assert(   (none >>= pure) == none)

// associativity law: ma flatMap f flatMap g = ma flatMap (a => f(a) flatMap g)
assert(   ((f(a) >>= g) >>= h) ==        (f(a) >>= (x => g(x) >>= h)))
assert( ((3.some >>= g) >>= h) ==      (3.some >>= (x => g(x) >>= h)))
assert(   ((none >>= g) >>= h) == (none >>= ((x:Int) => g(x) >>= h)))
```

```scala
extension[A,B](oa: Option[A])
  def >>= (f: A => Option[B]): Option[B] =
    oa flatMap f
```

And here are the **monad laws** expressed in terms of **Kleisli composition** (the **fish operator**).

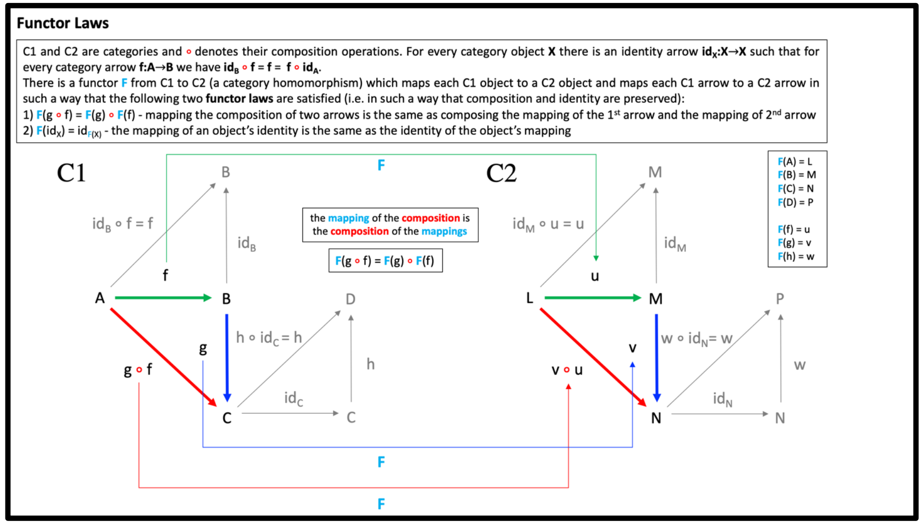



```scala
// left identity law: pure >=> f == f
assert( (pure[String] >=> f)(a) == f(a) )

// right identity law: f >=> pure == f
assert( (f >=> pure)(a) == f(a))

// associativity law : f >=> (g >=> h) == (f >=> g) >=> h
assert( (f >=> (g >=> h))(a) == ((f >=> g) >=> h)(a) )
```

```scala
extension[A,B,C](f: A => Option[B])
  def >=> (g: B => Option[C]): A => Option[C] =
    a => f(a) >>= g
```

If you are new to functor laws and/or monad laws you might want to take a look at some of the following

https://www2.slideshare.net/pjschwarz/functor-laws



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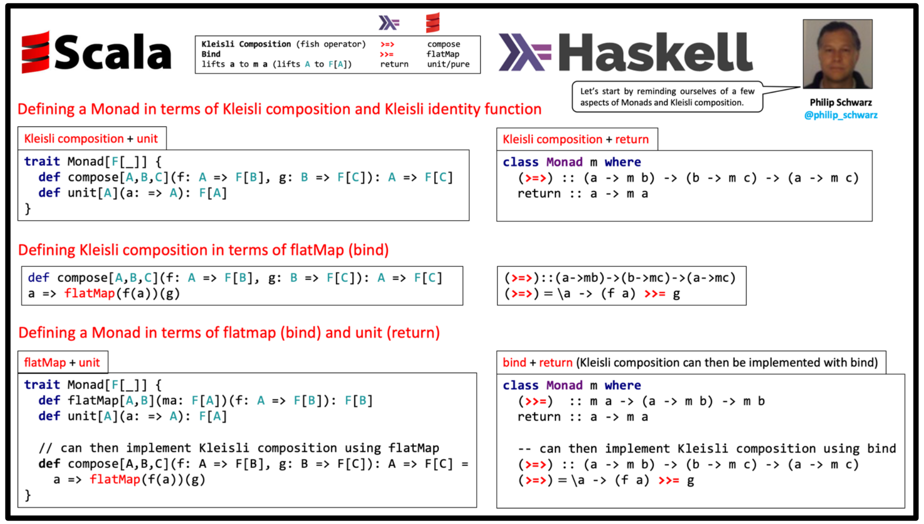
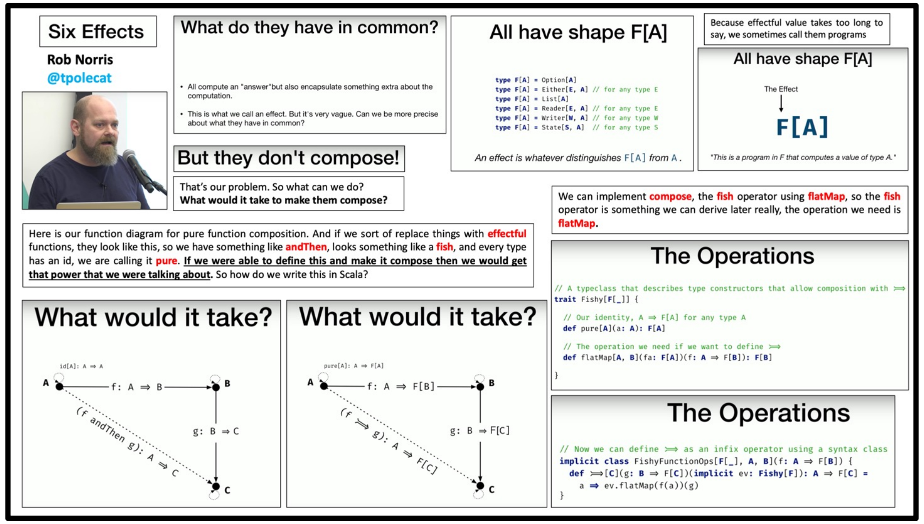


https://www2.slideshare.net/pjschwarz/rob-norrisfunctionalprogrammingwitheffects



That’s all. I hope you found it useful.

@philip_schwarz